QCD@Work 2003 - International Workshop on QCD, Conversano, Italy, 14–18 June 2003

Non factorizable Effetcs in $B \to \chi_{c0} K^-$ from Charmed Meson Rescattering*.

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The $B^- \to \chi_{c0} K^-$ decay which has no visible factorizable amplitude, could be induced by the Cabibbo-allowed, color-favored $B^- \to D_s D^{*0}$, $B^- \to D_s^{*0} D^0$ and $B \to D_s^* D^*$ via the rescattering of these charmed mesons to $\chi_{co} K^-$. In this talk I would like to discuss a recent calculation [1] of these effects for $B^- \to \chi_{c0} K^-$ and $B^- \to J/\psi K^-$ decays. We find that charmed scattering effects seem capable of producing a large $B^- \to \chi_{c0} K^-$ branching ratio measured by the Babar and Belle Collaboration and make a significant contribution to the $B^- \to J/\psi K^-$ branching ratios in agreement with experiments.

1 Introduction

Understanding colored-suppressed B decays is a challenging problem in B decays. It is well-known that colored-suppressed non leptonic B decays have a large branching ratios compared with naive factorization model. The effective Wilson coefficient $a_2 = c_2 + c_1/N_c$ is far smaller than the experimental value found from the measured branching ratios, like $B^0 \to D^0 \pi^0$, $B^0 \to D^0 \rho^0$ and also for $B^- \to J/\psi K^-$ decays. Improved QCD factorization could produce a larger a_2, but the predicted branching ratios for these colored-suppressed decays are still below the measured values, indicating possible nonfactorizable terms. Another evidence could come from the decay $B^- \to \chi_{c0} K^-$ with a large branching ratio measured by Belle[2] and Babar[3] Collaboration:

$$\begin{aligned} \mathrm{BR}(B^- \to \chi_{c0} K^-) &= (6.0^{+2.1}_{-1.8}) \times 10^{-4} (\mathrm{Belle}) \\ \mathrm{BR}(B^- \to \chi_{c0} K^-) &= (2.4 \pm 0.7) \times 10^{-4} (\mathrm{Babar}) \end{aligned} \quad (1)$$

which is comparable to the $B^- \to J/\psi K^-$ branching ratio of $(10.0 \pm 0.5) \times 10^{-4}$[4]. This is a big surprise since there is no appreciable factorizable contribution to this decay [5]. In fact, in the naive factorization model, because of the conservation of the vector current $\bar{c}\gamma^\mu c$, the matrix element $< 0|\bar{c}\gamma^\mu c|\chi_{c0} >= 0$ and the decay amplitude $B^- \to \chi_0 K^-$ vanishes. The large branching ratios for this decay could be an evidence for a non factorizable contribution in non leptonic B meson decay with charmonium in the final state. One possible non factorizable effects could be induced by the Cabibbo-allowed, color-favored $B \to D_s D^*$ and $B \to D_s^* D^*$ decays via the rescatterings of charmed mesons into charmnonium and K or K^* meson in the final state (inelastic FSI effects). In fact, the Cabibbo-allowed, color-favored B decays to charmed mesons, like $B \to D_s D^*$ and $B \to D_s^* D^*$ etc. with branching ratios a few times 10^{-2} would be the dominant contribution to the absorptive part of the $B^- \to \chi_{c0} K^-$ and $B^- \to J/\psi K^-$ decay amplitudes. This is a rare situation in non leptonic B decays, similar to the $B \to K\pi$ decays for which non factorizable contributions have been estimated in recent work [6] in which a large absorptive part and a large CP asymmetry for $B \to K\pi$ and $B \to \pi\pi$ amplitude are obtained. The idea that long-distance inelastic FSI effects could be present in heavy meson decays due to charmed meson rescattering process has been considered in the past, for $B \to \pi\pi$ [7], for OZI-suppressed heavy quarkonium decays [8] and for $B_s \to \gamma\gamma$ decay [9], As mentioned, the large branching ratios for the Cabibbo-allowed, color-favored two-body B decays with charmed meson in the final state, e.g $B \to D_s^* D^*$ decay, make the rescattering effects for $B \to K\pi$, $B^- \to \chi_{c0} K^-$ and $B^- \to J/\psi K^-$ decay more important than for other OZI-suppressed heavy quarkonium decays. In other word, charmless B decays and charmonium B decay with K or K^* in the final state are favorable decays to look for inelastic FSI effects. In a recent work [1], we computed the non factorizable $D_s D^{*0}$, $D_s^* D^0$ and $D_s^* D^{*0}$ rescattering terms for the $B^- \to J/\psi K^-$ and $B^- \to \chi_{c0} K^-$ decays and obtain large branching ratios in more or less agreement with experiments. Before presenting the calculations, I would like to discuss the QCD factorization for $B^- \to J/\psi K^-$ decay.

2 $B^- \to J/\psi K^-$ in QCD factorization

The effective Hamiltonian for nonleptonic B decays:

$$\mathcal{H}_{\mathrm{eff}} = \frac{G_F}{\sqrt{2}} [V_{ub} V_{us}^* (c_1 O_{1u} + c_2 O_{2u}) + V_{cb} V_{cs}^* (c_1 O_{1c} + c_2 O_{2c})] - \sum_{i=3}^{10} ([V_{ub} V_{us}^* c_i^u + V_{cb} V_{cs}^* c_i^c + V_{tb} V_{ts}^* c_i^t) O_i] + \mathrm{h.c.} \quad (2)$$

where the superscripts u, c, t denote the internal quark. The tree-level $(V-A) \times (V-A)$ operators are,

$$O_{1q} = \bar{q}\gamma_\mu (1-\gamma_5) b \bar{s}\gamma^\mu (1-\gamma_5) q,$$

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$$O_{2q} = \bar{q}\gamma_\mu(1-\gamma_5)q\bar{s}\gamma^\mu(1-\gamma_5)b. \quad (3)$$

with $q = u, c$. For the penguin operators, we rewrite $O_3 - O_6$, using the Fierz transformations, as follows:

$$\begin{aligned} O_3 &= \sum_{q=u,d,s,c,b} \bar{s}\gamma_\mu(1-\gamma_5)b\bar{q}\gamma^\mu(1-\gamma_5)q, \\ O_4 &= \sum_{q=u,d,s,c,b} \bar{s}\gamma_\mu(1-\gamma_5)q\bar{q}\gamma^\mu(1-\gamma_5)b, \\ O_5 &= \sum_{q=u,d,s,c,b} \bar{s}\gamma_\mu(1-\gamma_5)b\bar{q}\gamma^\mu(1+\gamma_5)q, \\ O_6 &= -2\sum_{q=u,d,s,c,b} \bar{s}(1+\gamma_5)q \end{aligned} \quad (4)$$

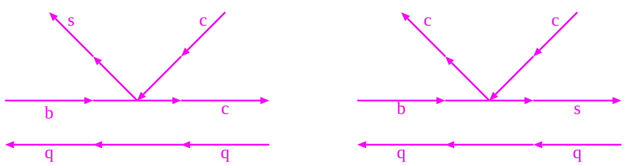

Figure 1. factorization contribution to $B^- \to J/\psi K^-$ decay

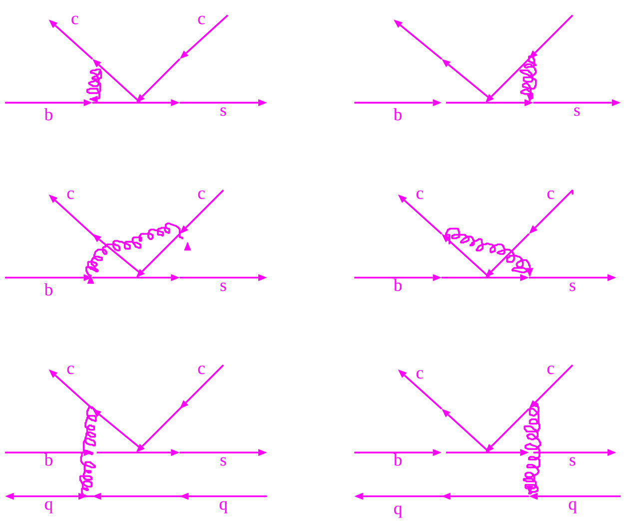

Figure 2. Vertex and spectator corrections to $B^- \to J/\psi K^-$ decay

The factorization approximation (Fig.1) is obtained by neglecting in the Lagrangian terms which are the product of two color-octet operators after Fierz reordering of the quark fields. The effective Lagrangian for non leptonic decays are then given with c_i replaced by a_i. For $N_c = 3$, $m_b = 5\,\mathrm{GeV}$, we have [11, 12]

$$\begin{aligned} a_1 &= \ 1.05, & a_2 &= \ 0.07, \\ a_4 &= -0.043 - 0.016i, \\ a_6 &= -0.054 - 0.016i. \end{aligned} \quad (5)$$

Only $O_{2c} = \bar{c}\gamma_\mu(1-\gamma_5)c\bar{s}\gamma^\mu(1-\gamma_5)b$ contributes to $B^- \to J/\psi K^-$ decay (neglecting penguins):

$$\begin{aligned} A(B^- \to J/\psi K^-) \;=\; & \frac{G_F}{\sqrt{2}} V_{cb}V_{cs}^*(a_2)\, f_{J/\psi} m_{J/\psi} \\ & \times F_1^{BK}(m_{J/\psi}^2)(2\varepsilon^* \cdot p_B), \end{aligned} \quad (6)$$

With $f_{J/\psi} = 405 \pm 15\,\mathrm{MeV}$, $|V_{cb}| = 0.040$,$|V_{cs}| = 0.9735$, $F_1^{BK}(m_{J/\psi}^2 = 0.70$ one gets a branching ratio 1/10 of the measured value of $(1.00 \pm 0.1) \times 10^{-3}$. In terms of a_2 and $F_1^{BK}(m_{J/\psi}^2)$. the branching ratio is then

$$\mathrm{BR(B^- \to J/\psi K^-) = 3.04 \times 10^{-2}(a_2\, F_1^{BK}(m_{J/\psi}^2))^2} \quad (7)$$

One would need a_2 in the range $0.25 - 0.40$ depending on the value for the $B \to K$ form factor $F_1^{BK}(m_{J/\psi}^2)$ to produce the experimental value. For example, from the $B^- \to J/\psi K^-$ branching ratio, one gets $a_2 = 0.38$ according to Ref.[10] while in [13] an effective $a_2 = 0.25$ could also give the correct branching ratio. Non factorizable terms due to vertex correction and spectator interactions obtained from QCD factorization represented by diagrams in Fig.2 have been done for $B^- \to J/\psi K^-$ decay [14, 15] who give, in terms of the vertex correction f_I and the hard spectator interaction term f_{II},

$$\begin{aligned} a_2 = c_2 + \frac{c_1}{N_c} + \frac{\alpha_s}{4\pi}\frac{C_F}{N^c}c_1\Big(-18 + 12\ln\frac{m_b}{\mu} \\ + f_I + f_{II} + \frac{F_0^{BK}(m_{J/\psi}^2)}{F_1^{BK}(m_{J/\psi}^2)} g_I\Big) \end{aligned} \quad (8)$$

with f_I, f_{II} and g_I given in [14, 15] . This result shows that a_2 , as in $B \to \pi\pi$ decays [16], gets a large contribution from the hard spectator interaction term (f_{II}) which can increase a_2 to $0.15 - 0.20$, a significant improvement over the naive factorization model. One could vary the form factor $F_1^{BK}(m_{J/\psi}^2)$ to get a bigger a_2 . However a large $F_1^{BK}(m_{J/\psi}^2)$ would imply a large $F_1^{B\pi}(m_\pi^2)$ and hence a too large $B \to \pi^+\pi^0$ branching ratio. Thus taking the theoretical uncertainties on the $B \to K$ form factors into account, it seems that we need a large a_2 to explain the $B^- \to J/\psi K^-$ branching ratio. For $B^- \to \chi_{c0}K^-$ decay, recent work [17] indicates that there are infrared divergence problems in the vertex correction and spectator interaction terms in QCD factorization. We now turn to the calculation of the charmed meson rescattering effects for $B^- \to \chi_{c0}K^-$ and $B^- \to J/\psi K^-$ decays.

3 $B^- \to \chi_{c0}K^-$ from charmed meson rescattering

The decay $B^- \to \chi_{c0}K^-$ can occur through the Cabibbo-allowed, colored-favored $B^- \to D_s^- D^{*0}$ decay followed by

the rescattering $D_s^- D^{*0} \to \chi_{c0} K^-$ as well as through the $D_s^{*-} D^0$ and $D_s^{*-} D^{*0}$ intermediate states which rescatter into $\chi_{c0} K^-$ final state.

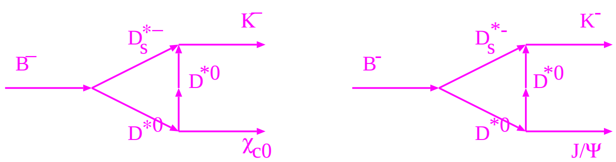

Figure 3. A rescattering diagram for $B^- \to \chi_{c0} K^-$ and $B^- \to J/\psi K^-$

Experimentally the $B^- \to D_s^- D^{*0}$ decay rate is about a factor of $20 - 50$ bigger than the $B^- \to \chi_{c0} K^-$ so these charmed meson intermediate states give the dominant contribution to the absorptive part in the unitarity relation. For the D_s^{*-}, D^{*0} intermediate state, the absorptive part is given by

$$\mathrm{Im} A_1 = \frac{|p_1|}{16\pi m_B} \int_{-1}^{+1} dz A(B^- \to D_s^{*-} D^{*0}) \times A(D_s^{*-} D^{*0} \to \chi_{c0} K^-) \quad (9)$$

where p_1 is the of the charmed meson 3-momentum in the rest frame of the B meson. The amplitude $A(B^- \to D_s^{*-} D^{*0})$ can be computed using the factorization model which describe rather well the measured branching ratios for the Cabibbo-allowed, color-favored two-body B decays to charmed mesons [18]. Writing

$A(B^- \to D_s^{*-} D^{*0}) = \langle D_s^{*-} D^{*0} | \mathscr{H}_{\rm eff} | B^- \rangle$ and

$$\langle D_s^{*-} D^{*0} | \mathscr{H}_{\rm eff} | B^- \rangle = \frac{G_F}{\sqrt{2}} V_{cb} V_{cs}^* a_1 \times \langle D^{*0} | (V-A)^\mu | B^- \rangle \langle D_s^{*-} | (V-A)_\mu | 0 \rangle \quad (10)$$

with

$$\begin{aligned} < 0 | \bar{q}_a \gamma^\mu \gamma_5 c | D_a(v) > &= f_{D_a} m_{D_a} v^\mu \\ < 0 | \bar{q}_a \gamma^\mu c | D_a^*(v, \varepsilon) > &= f_{D_a^*} m_{D_a^*} \end{aligned} \quad (11)$$

and

$$\begin{aligned} < D^0(v') | V^\mu | B^-(v) > &= \sqrt{m_B m_D}\, \xi(v \cdot v')(v + v')^\mu \\ < D^{*0}(v', \varepsilon) | V^\mu | B^-(v) > &= -i \sqrt{m_B m_{D^*}}\, \xi(v \cdot v') \\ &\quad \times \varepsilon_\beta^*\, \varepsilon^{\alpha\beta\gamma\mu} v_\alpha v'_\gamma \quad (12) \\ < D^{*0}(v', \varepsilon) | A^\mu | B^-(v) > &= \sqrt{m_B m_{D^*}}\, \xi(v \cdot v') \varepsilon_\beta^* \\ &\quad \times [(1 + v \cdot v') g^{\beta\mu} - v^\beta v'^\mu] \end{aligned}$$

We next evaluate the scattering amplitude $A(D_s^{*-} D^{*0} \to \chi_{c0} K^-)$ using the $t-$channel D^0, D^{*0} exchange Born term shown in diagrams of Fig.3.

The couplings DD^*K and D^*D^*K for the strong vertex in the scattering amplitude can be expressed in terms of a parameter g in HQET[19] and can be extracted from the $DD^*\pi$ coupling using $SU(3)$ and extrapolated from the soft pion limit.

$$\begin{aligned} < D^0(p) K^-(q) | D_s^{*-}(p+q, \varepsilon) > &= g_{D_s^{*-} D^0 K^-} (\varepsilon \cdot q) \\ < D^{*0}(p, \eta) K^-(q) | D_s^{*-}(p+q, \varepsilon) > &= i \varepsilon^{\alpha\beta\mu\gamma} p_\alpha \varepsilon_\beta q_\mu \eta_\gamma^* \\ &\quad \times g_{D_s^{*-} D^{*0} K^-} \end{aligned} \quad (13)$$

with

$$g_{D_s^{*-} D^0 K^-} = -2 \frac{\sqrt{m_D m_{D_s^*}}\, g}{f_K}, g_{D_s^{*-} D^{*0} K^-} = 2 \frac{\sqrt{m_{D_s^*} m_{D^*}}\, g}{f_K} \quad (14)$$

As g is defined as the coupling in the decay $D^* \to D\pi$, its soft pion value is known from experiment which gives $g = 0.59 \pm 0.01 \pm 0.07$. This value supports a previous prediction using soft pion theorem which gives $g = 0.75$ [20]. We include off-shell effects for each strong vertex with coupling g_i by a form factor taken as [21, 22] $F_i(t) = (\Lambda_i^2 - m_{D*}^2)/(\Lambda_i^2 - t)$. These form factors also act as suppression factor for the charmed meson rescattering ammplitudes which, being exclusive process at high energy (in the B mass region), should be suppressed. For the $\chi_{c0} DD$ and $\chi_{c0} D^* D^*$ vertex, as with the $D^* DK$ vertex, we extrapolate the on-shell couplings to off-shell t region with a form factor similar to $F_i(t)$. The on-shell couplings are obtained assuming the dominance by the nearest scalar meson state for the scalar $\bar{c}c$ current. The couplings are then

$$g_{\chi_{c0} DD} = -2 \frac{m_D m_{\chi_{c0}}}{f_{\chi_{c0}}}, \quad g_{\chi_{c0} D^* D^*} = 2 \frac{m_{D^*} m_{\chi_{c0}}}{f_{\chi_{c0}}} \quad (15)$$

with $f_{\chi_{c0}} = 519 \pm 40\,\mathrm{MeV}$ from QCD sum rules [1] . Similarly, the $J/\psi DD$ and $J/\psi D^* D^*$ couplings are obtained with J/ψ dominance for the charm quark contribution to the electromagnetic form factor of the D meson at zero momentum transfer . We find

$$g_{J/\psi DD}^2 / 4\pi = 5. \quad (16)$$

though large. but not as large as the value $g_{\psi(3770)DD}^2 / 4\pi = 17.5$ obtained from the width of the $\psi(3770)$. For comparison, $g_{\phi K^+ K^-}^2 / 4\pi = 1.66$. Thus there is evidence that charmonium 1^{--} states couple strongly to charmed mesons [8]. One consequence of the large coupling $g_{\psi(3770)DD}$ is that the rescattering effects would be more important in $B^- \to \psi(3770) K^-$. The small leptonic decay constant of the $\psi(3770)$ furthermore makes the factorizable term less significant so that most of the contribution wouild come from the non factorizable terms. Thus one should see the decay $B^- \to \psi(3770) K^-$ with a branching ratio comparable to $B^- \to \chi_{c0} K^-$ branching ratio.

4 Results

In Table 1, we give the absorptive ImA and dispersive part ReA for the rescattering contributions.

Table 1. Numerical results for the rescattering contribution in 10^{-7} GeV (A) and in 10^{-7} ($\tilde{A}$)

$B^-\to K^-\chi_{c0}$	ReA	ImA	Λ_i (GeV)
	$-(0.9-1.7)$	$-(0.5-1.0)$	2.5
	$-(1.4-2.7)$	$-(0.6-1.2)$	2.8
$B^-\to K^-J/\psi$	Re$\tilde{A}$	Im$\tilde{A}$	Λ_i (GeV)
	$(0.1-0.2)$	$-(0.5-0.9)$	2.5
	$(0.2-0.3)$	$-(0.9-1.7)$	2.8

The experimental amplitudes are

$$\begin{aligned} |A_{\rm exp}| &= (3.39\pm 0.68)\times 10^{-7}\,{\rm GeV}, \quad ({\rm Belle}) \\ &= (2.1\pm 0.3)\times 10^{-7}\,{\rm GeV}, \quad ({\rm Babar}) \end{aligned}$$

for $B^- \to \chi_{c0}K^-$. For $B^- \to J/\psi K^-$, we have:

$$|\tilde{A}_{\rm exp}| = (1.41\pm 0.68)\times 10^{-7}, \quad ({\rm PDG}) \tag{17}$$

where $\tilde{A}$ defined as

$$A(B^- \to J/\psi K^-) = \tilde{A}\,\varepsilon^*\cdot q \tag{18}$$

We see from Table 1 that both the real and imaginary parts of the $B^- \to \chi_{c0}K^-$ and $B^- \to J/\psi K^-$ decay amplitudes are in the range of the measured values.

5 Conclusion

Charmed meson rescattering seems capable of explaining the large branching ratio for the decay $B^- \to \chi_{c0}K^-$. It also makes an important contribution to the $B^- \to J/\psi K^-$ decay rate which would be too small in QCD factorization. The recent observation of the decay $B^+ \to \psi(3770)K^+$ at Belle [23] with a branching ratio of $(0.48\pm 0.11\pm 0.12)\times 10^{-3}$ could be another strong evidence of non factorizable terms in non leptonic B decay with charmonium in the final state. One could look for more evidence [24] in other B decays to $P-$wave charmonium states such as the χ_{c2} and the h_c meson which have no visible factorizable contributions.

Acknowledgments

I would like to thank G. Nardulli, P. Colangelo and the Organisers of the QCD@Work 2003 Workshop for the warm hospitality extended to me at Conversano.

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